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SOIL PROFILE STUDIES IN RELATION TO SITE REQUIREMENTS OF BLACK LOCUST AND BLACK WALNUT

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Recent appreciation of land-use and conservation problems in the Central States has led to a greatly expanded public program of forest restoration. With the rapid increase in tree planting that ultimately may cover millions of acres of non-agricultural lands, it is necessary to select those species that will best serve the purpose of planting, whether it be for productive forest crops or for protective forest cover. It is essential that the selected species be adapted to the local conditions of climate, soil, and site; otherwise the planted trees cannot be expected to become established and grow successfully.

In the past many foresters have not given due consideration to the soil and moisture requirements of various tree species, nor to the changes of site caused by soil erosion and impoverishment that have taken place following removal of the virgin forest. In many instances it is no longer entirely safe to plant the species that formerly occupied the site. A large portion of the failures in reforestation may be attributed to lack of understanding of the site requirements of trees, and to the lack of suitable methods for appraising given site conditions before planting. In an effort to obtain this essential information, a study of soil properties correlated with tree growth has been started at the Central States Forest Experiment Station. This progress report summarizes the results of the first phases of the investigation.

Scope of Study. To initiate this study, the choice of two species extensively planted in this region, black walnut and black locust, gave promise of covering an extremely wide range of variations in the site requirements of upland hardwood species. It was thought that important soil and site conditions influencing growth of hardwoods would be brought to light, and that these might differ greatly between species. This preliminary study has resulted in a better understanding of conditions affecting moisture relationships which appear to exert great influence on the successful growth of hardwoods. A surprisingly similar reaction to these factors has been found for both species studied.

The black walnut plantation plots serving as the basis for this investigation were established by Kellogg (3) in 1928-1930, during a growth and yield study of black walnut in Ohio, Indiana, Kentucky, and Iowa. The black locust plantation plots were also established by Kellogg and by Hall (2) in 1930-1932, during their investigations of black locust growth and locust borer control, respectively. The locust plots were found from southern Michigan to southwestern Tennessee, and from western Illinois to eastern New York.

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The study consisted of collection and analysis of soil and site data from plantation plots for correlation with known rates of tree growth. The trees had been measured, their volume computed, and site index calculated for each of the locust and walnut plots. The accepted measure of site used in this study is the average height to which dominant trees grow in fifty years. As a check on this method of site quality evaluation, the volume yield of 100 plots was calculated for mean annual growth in cubic feet per acre, and correlated with the height-age site index. The correlation coefficient was .85 $\pm$ .02, indicating that the site index method provides a relatively reliable measure of site quality.

The soil data gathered from each plantation plot were divided into two parts - physical and chemical. In the study of physical factors the soil type was determined and the soil profile was examined for thickness, compactness, plasticity, texture, drainage, and color. The chemical study included determination of total nitrogen, organic carbon, water-soluble phosphorus, and acidity by the quinhydrone-calomel electrode method. Table 1 gives a sample of the data collected for a few of the 135 black locust plots and the 120 black walnut plots studied.

Analysis And Discussion of Data on Physical Soil Properties

Soil Type. The results of this study have shown conclusively that soil types as mapped cannot be used indiscriminately as a criterion for evaluating site quality. In the broadest aspect a knowledge of soil types is valuable, but every soil surveyor knows that it is impossible to map all local variations within a soil type. Differences, especially of the properties and depths of the subsoil, are so numerous and diverse that the surveyor must set arbitrary limits of variation wide enough to cover the gamut of changes within the soil type. Slight variations in the soil are often critical factors in successful tree growth.

In general, certain of the lighter classes of soils, such as silt loams and sandy loams, predominated where the best growth of walnut and locust was found. The clays, silty clay loams, and heavier soils predominated in the poorer site range. If one could be sure of having the typical soil type as defined by the surveyor, he could place considerable credence on its forecasting possibilities as regards tree growth, but in many instances this cannot be ascertained without a detailed examination of each individual area. This is no reflection on the excellent work of the soil surveyor, who can supply the information needed if he has the opportunity to make the survey in the necessary detail.

Thickness of Soil Horizons. The thickness or depth of the surface soil (A horizon) is in general a measure of the cumulative effect of weathering, as well as of the extent of erosion, and should be a valuable indication of site quality. Analysis of the plot data shows that deep surface soil favors the growth both of locust and walnut. Apparently black locust is more susceptible to the influence of site deterioration than was commonly believed.

No relation was observed between depth of the subsoil (B horizon) and growth either of walnut or locust. This was to be expected, because mere thickness unrelated to compactness or plasticity means little in relation to aeration or drainage.

Subsoil Properties. Measurements of compactness, plasticity, drainage, and oxidation were taken only in the subsoil horizon. The A horizon or upper soil layer was entirely absent in some plots as a result of erosion, and in order to secure comparable data it was necessary to examine the lower horizons. The subsoil, with its accumulation of colloidal material, often more clearly records the status of soil evolution than does the surface soil. The color of the subsoil presents a clear picture of the extent of aeration and consequent oxidation. The character of the subsoil determines very largely how effectively the soil profile is drained. As far as physical structure is concerned, therefore, aside from the early period of tree establishment, it is the subsoil that most effectively influences growth.

An evaluation of compactness, plasticity, drainage, and oxidation was made on the basis of the following keys:

COMPACTNESS INDEX KEY

1. Non-coherent when moist - loose
2. Slightly coherent when moist
3. Mellow when moist
4. Friable when moist
5. Moderately compact when moist
6. Very compact when moist
7. Extremely compact when moist

PLASTICITY INDEX KEY

1. Non-plastic when wet
2. Very slightly plastic when wet
3. Slightly plastic when wet
4. Moderately plastic when wet
5. Highly plastic when wet
6. Very highly plastic when wet

DRAINAGE INDEX KEY

1. Moraines or loose sand
2. Terraces - no illuviation
3. Rolling upland
4. Level upland
5. Low areas
6. Swampy areas with high water table
7. Water-logged areas

OXIDATION INDEX KEY

1. Red - brown
2. Yellowish brown
3. Brownish yellow
4. Yellow
5. Drab and yellow
6. Drab and blue
7. Blue

The compactness and plasticity keys were taken from the recommendations of J. C. Russell and committee (5). The drainage index is self-explanatory and was devised to describe conditions as they were encountered in the field. The oxidation index key is based on the color of the subsoil and is postulated on the theory that well oxidized soils are red or brown and reduced soils are drab to blue in color. The index key numbers corresponding to the soil condition of the site were assigned in each case and statistically correlated with tree growth as expressed by site index. (See Table 1.)

Compactness. Compactness is a function of texture, structure, moisture content, root penetration, and to a certain extent, chemical composition. Its manifestation in the field was exhibited in the degree of hardness experienced in digging a hole and the difficulty encountered in crushing lumps of soil in the hand. Compactness of the subsoil was found to be detrimental to the growth of black walnut and very greatly reduced the growth rate of black locust. It was observed also during the field work of this investigation that compaction of the surface soil by livestock invariably resulted in poorer growth both of locust and walnut. It is obvious that compaction of soil results in a reduction of the rate of aeration, without which mineral elements are not made available for the tree roots. A tight soil also prevents water absorption and penetration, and otherwise interferes with soil-water movement.

Plasticity in the subsoil generally is a measure of the extent to which a soil has been illuviated or drained. Estimation of this factor in the field was made on the basis of the ease with which the moist soil could be rolled into a wire or the difficulty experienced in moulding a lump of it in the hands.

Plasticity is an indication of soil colloid content. Up to a certain point colloids are beneficial to tree growth because they prevent excessive drainage and increase retention of soluble compounds, but beyond that amount they are often a growth deterrent because they decrease the rate of aeration, increase the percentage of rainfall run-off, and accentuate the difficulty of root development and penetration. When the field data on plasticity of the black locust subsoil were correlated with site index, it was found that heavy surface soil or heavy subsoil depressed growth of black locust. With black walnut the same was true of the surface soil, but the relationship was not definite for the subsoil.

TABLE 1

SAMPLE OF GROWTH AND SOIL DATA FROM BLACK LOCUST AND BLACK WALNUT PLOTS

Plantation Plots	Site Index	Oxidation Index	Drainage Index	Plasticity Index	Compactness Index	Thickness A Hor. Inches	Thickness B Hor. Inches	pH A Horizon	pH B Horizon	Nitrogen-parts per million-A Hor.	Carbon-parts per million-A Hor.	Phosphorus per acre (2 million pounds)	Per cent Colloid A Horizon	Per cent Colloid B Horizon	Soil Type
(Plot No.)		(Index Key No.)													
								BLACK LOCUST							
*N.Y. 321	133	1	2	1	1	24	0	5.2							Hudson sand
Ind. 255	117	2	2	4	3	48	0	7.0		1720	16728	30	8		Genesee silt loam
Ind. 206	98	2	3	4	3	6	40	5.6	5.8	1500	9555	2.5	12	10	Cincinnati silt loam
Ohio 72	95	3	3	4	4	6	39	5.9	5.3	2070	22386	8	17	23	Wooster silt loam
Ind. 214	94	3	3	4	4	0	48		5.3	1680	15288	6		14	Fairmount silty clay loam
Ohio 43	92	3	3	4	4	6	34	6.8	7.1	1550	17745	6	13	13	Cincinnati silt loam
Ind. 217	92	2	3	5	6	5	67	5.3	5.7	850	10374	6	13	20	Cincinnati silty clay loam
Ohio 18	54	3	3	4	5	6	24	7.2	7.6	2250	23593	20	16	11	Miami clay loam
Ohio 134	52	2	3	4	5	7	21	5.6	6.0	1370	13377	15	14	19	Muskingum silty clay loam
Ohio 7	50	4	4	5	6	4	14	6.3	6.6	2190	22932	20	15	22	Rodman silty clay loam
Ohio 112	49	5	5	4	5	7	35	5.9	6.8	1800	15561	6	13	13	Wabash clay loam
Ohio 159	38	6	6	6	7	0	28		6.4	1140	10101	15		13	Abington silty clay loam
Ohio 164	38	5	5	5	5	8	16	6.2	6.6	1250	13650	10	14	15	Crosby clay loam
**Tenn. 292	37	1	1	1	1	60	0	5.9							Lexington sand
								BLACK WALNUT							
Ind. 3	76	2	2	4	4	20	20	6.9	8.2	1440	15288	10	11	25	Fox sandy clay loam
Ohio 28	71	2	2	2	3	20	0			1370	19110	100	9	12	Bellfontaine sandy loam
Iowa 93	70	3	3	4	4	15	14	6.8	6.1	2740	33579	25	9	14	Tama silty clay loam
Ind. 9	45	3	3	3	5	12	32	7.6	6.9	2610	17575	20	10	23	Fincastle silt loam
Ohio 118	45	5	5	4	4	10	20	6.9		3420	45318	90	21	27	Brookston clay

*Sandy soil with good moisture
**Sandy soil excessively drained

Plasticity Number. Forty samples of subsoil from the locust plots were selected for the determination of plasticity number. This measure of plasticity was determined in the laboratory and represents the difference between two moisture percentages: the upper, at which a soil will just flow, and the lower, at which it cannot be rolled into a 1/8-inch wire without crumbling. In this connection, it is probably an expression of colloid content projected into terms of soil compactness and drainage. Ten of these forty samples were selected from plots having the highest site indexes, ten from those of the lowest site indexes, and two groups of ten each from the plots of intermediate site indexes. The determinations, although showing a rather wide spread within each group, indicated an unmistakable relationship with site index closely paralleling the field estimate of plasticity. This test signifies that subsoils having a high plasticity number decrease growth rate for black locust. The test was not used for black walnut soils.

Drainage. Several factors were involved in assigning drainage index numbers to plots. Compactness, plasticity, aeration, and oxidation are very closely related to drainage, and it is difficult to consider one without the others. In recording the index of drainage, considerations of topography, nearness to drainage systems, soil texture and structure were given weight. The estimation of drainage, of course, overlaps that of other soil factors, but it gives an additional approach to site appraisal, and as such is valuable. Drainage was found to be highly significant in the case both of locust and walnut. Unsatisfactory growth invariably occurred on poorly drained soils.

Correlation of growth with the drainage index key encountered difficulties, however, in the case of excessively drained soils, because they also were poor sites for locust or walnut. A preliminary plotting of soil properties with site indexes showed that sands and thin soil over rock did not always follow the general trend of other plots. Some plots on sandy soil showed very high growth rates and some very low, even when most of the other soil properties were similar. Plots on thin soil over rock never showed as good growth as the soil properties themselves seemed to justify. This condition held true both for locust and walnut, and obviously was the result of excessive drainage. If the sand plot had a high water table or was located in a moist, sheltered cove or slope, the site index was usually very high; if the sand plot was on an excessively drained ridge, the growth rate was low. Specifically, the site index of the New York black locust plot 321 on Hudson sand was 133. (See Table 1.) This plot was on an alluvial fan at the foot of a gneiss ridge in the Hudson River Valley. The location favored optimum moisture conditions. Tennessee locust plot 292 on Lexington sand had a site index of 37, but the location was a dry, exposed slope with excessive underdrainage. Because sandy soil and shallow soil over rock introduced a variable which interfered seriously with correlation of other factors, it seemed advisable to segregate them in comparison with other plots.

Oxidation as Indicated by Color of Subsoil. It became apparent, as the investigation proceeded, that those soil properties which are conducive to drainage and aeration were in this region usually indicated by the subsoil color. The color of the subsoil generally is dependent on the state of oxidation, and this in turn is influenced by the extent to which the soil is aerated. A site with poor drainage because of heavy subsoil and a

high water table through a comparatively long period of the year has poor aeration. As a consequence, it is likely to be blue or drab in color because the oxides of iron remain in the ferrous condition. If the soil has good aeration the ferrous compounds are oxidized to red ferric oxides and the subsoil becomes red or brown. This change in color is the cumulative effect of years of aeration and not of short periods, although when exposed to the air the soil will change its color quite rapidly in some cases.

This relationship of subsoil color to growth was strikingly demonstrated by many plots. Frequently the subsoil varied within rather small distances in the same plantation, and commonly the more thriftily-growing trees were associated with a brown or reddish-brown subsoil, whereas the shorter, less thrifty trees were found on a blue, drab, or gray-mottled subsoil. Often there was no apparent difference on the surface unless one took into consideration a difference in level of a few inches or at most a foot or two. Little swales or depressions, however, often were indicative of a tighter and a more reduced subsoil where the trees had shallower root systems and less thrifty stems. The presence of a reddish brown or brown subsoil was very often associated with a coarse structure, although this was not always true. In some cases, soils high in clay content showed a good structure, perhaps because of good underdrainage. In general, however, good oxidation and porous structure were associated with good growth of locust and walnut, whereas poor oxidation and compact structure were associated with poor growth. Similar depressing effects of reduced soils on apple tree growth and productivity have been observed in New York and reported by Bradfield, Batjer, and Oskamp (1). Tight, poorly aerated subsoils were observed by Sweet (6) to depress apple tree growth in the Ozarks.

Analysis And Discussion of Data on Chemical Soil Properties

When the problems of soil fertility and the relation of chemical properties to tree growth are considered on the basis of the data of this investigation, the results do not stand out significantly either for locust or walnut. Twenty-five soil samples were selected from the plots among the upper range of site indexes and twenty-five from the plots of poorest growth. Total nitrogen, organic carbon, phosphorus, and acidity (pH) were determined from these samples. There was little or no relationship shown between the amounts of the essential elements found in the soils of the plots examined and the growth of black locust or black walnut as indicated by site index.

Nitrogen - Black Locust. Six sample plots of excellent locust growth where meteorological influences could be assumed to be fairly constant (Indiana and Ohio Plots 255, 206, 214, 217, 72, and 43) were compared with six plots of much poorer growth (18, 134, 7, 112, 164, and 159) in the same region. The site indexes of the first set of plots ranged from 92 to 117, with an average of 98; those of the second set ranged from 38 to 54, with an average of 47. The pounds of nitrogen per million pounds of soil averaged 1562 for the plots of good growth and 1666 for those of poorer growth. The total pounds of nitrogen per acre in the upper twelve inches of soil were 3787 pounds for the first set of plots and 4305 pounds for the second set. The difference in the amounts of nitrogen could not be considered significant, yet the average site index of the first set of plots was more than twice that of the second set.

In any consideration of the relationship of the nitrogen content of soil to black locust growth, the fact that locust is a legume must be remembered. In this case either the nitrogen fixed must have been made available and quickly assimilated by the trees or else the minimum amount found as total nitrogen must have been above the limiting amount necessary for good growth. As a technical point this is important, but as a consideration in the choice of a locust planting site it is not. A soil relatively low in total nitrogen may still be a good site for locust.

When one considers the small amount of nitrogen necessary to produce a satisfactory growth of wood, the difficulty of securing correlation of growth with nitrogen content becomes evident. Those plots containing very large amounts of nitrogen would not contribute their influence in developing a high correlation coefficient because it is obvious that no amount of any element above that necessary to produce maximum growth would have any influence in showing growth increase. It is only within the range where nitrogen is limiting that one can hope to secure a high correlation figure with that variable. This investigation did not encounter such a condition within the plots studied.

Nitrogen - Black Walnut. The minimum amount of nitrogen per million pounds of soil found in the A horizon of walnut plots within the upper range of site indexes was 1370 pounds, or 6394 pounds per acre in the upper 12 inches. This particular plot (Ohio 28) had 10657 pounds total nitrogen per acre in its entire 20-inch A horizon. Such nitrogen content compares favorably with that in an average corn soil. These data might be interpreted to indicate that walnut needs a considerable amount of nitrogen for best growth, although they do not prove that walnut would not make good growth on a soil containing less nitrogen. However, in this rather extensive investigation no walnut plantation was found on a soil having less than 1000 pounds of nitrogen per million pounds of soil and the range in amount in the plots of good growth was very similar to that of the plots of poorest growth. Were data available for areas where planted walnut had failed and disappeared, more significant relationships might have been established.

Organic Carbon - Black Locust. It might be assumed, logically, that organic matter in the surface mineral soil would exert a great influence on locust growth, especially in the light of experience with agricultural crops, but a determination of organic carbon in the 50 above-mentioned samples disclosed no relationship with growth. In many instances the carbon content determined as organic carbon was a deep accumulation over long periods of time and the large amount did not exert an influence on growth in proportion to its magnitude. Specifically, in the case of a soil where there is an accumulation of organic matter to a depth of 8 to 20 inches, thoroughly disintegrated and diffused, the continuous water-holding capacity attributable to the organic matter may not be as great as in a soil where the accumulation of organic matter is much less, but where it is concentrated on the surface soil and in the immediate upper horizon. In the latter instance, the insulating effect against evaporation may be much greater than in the former, even though the actual amount of carbonaceous matter is less. In any event, the effect of organic carbon content was not commensurate with its amount.

Organic carbon - Black walnut. No significant correlation was observed between growth of black walnut and the amount of organic carbon in the surface horizons. Very wide variations occurred in the total amount of organic carbon in the upper 12 inches of the various sites. For instance, Ohio plot 28 and Iowa plot 93 contained 68,000 and 120,000 pounds of carbon, respectively, yet the site index for the former was 71 and for the latter 70. In the case of Indiana plot 9 and Ohio plot 118 the amounts were 64,000 and 163,000 pounds, respectively, and the site index of each was only 45.

The presence of data on prairie plots with soils high in organic carbon complicated the correlation. This soil was, of course, developed under conditions not indigenous to the natural habitat of black walnut. The presence of organic carbon in a forest soil is usually the result of favorable site conditions as regards temperature, exposure, and moisture evenly distributed during the growing season. Deep organic matter is usually found in the coves and sheltered spots in the woods and it was in such places that the best natural growth of walnut originally occurred. In the prairie soils the large amounts of organic matter were accumulated from grasses under conditions of rainfall unequally distributed over the year and in such a climate that grasses could survive better than trees.

Whether walnut will grow better on soil having a large amount of organic carbon cannot be determined on the basis of the data at hand. The fact that it was found naturally on soils well supplied with organic matter is indirect evidence that the species thrives under such conditions, but to say that the reason for its successful growth was carbon rather than some other element or factor would not be justified on the basis of this investigation.

Soluble Phosphorus - Locust and Walnut. The most that can be said concerning the relation of the soluble phosphorus content of the soil and the growth of black walnut or black locust is that even very small amounts of the element in the soluble form are no indication of low site quality. In other words, the amount of soluble phosphorus does not seem to have a significant relation to the growth of these two species. As little as 3 pounds of soluble phosphorus per acre was found on the better sites both of walnut and locust. Such an amount is extremely small as compared with that considered necessary for a good agricultural soil. Either this amount is not limiting or, as is more likely, a continuous supply of soluble phosphorus is made available as the growing season advances.

Soil Acidity by Quinhydrone Electrode - Locust and Walnut. Much research has been devoted to the effect of pH on legumes, and it has been accepted quite generally that soil acidity has an important influence on the growth of locust. The data of this investigation failed to show any correlation between pH and site index. In Table No. 2, the range of soil acidity has been given for groups of locust plots arranged according to site index classes. There is no significant difference between groups.

TABLE 2

Site Index Range	Range of pH - Black Locust Plots		
	A Horizon	B Horizon	C Horizon
90-140	5.1 to 7.8	4.6 to 7.1	5.4 to 6.4
70-90	4.6 to 8.0	4.6 to 8.1	4.9 to 7.4
50-70	4.8 to 8.0	4.9 to 8.2	5.3 to 8.0
35-50	4.8 to 7.0	4.8 to 8.2	5.0 to 8.0

Summary of 246 Determinations

On the basis of these data, it may be said that within the range of 4.6 to 8.2 there is no apparent relationship between pH and locust growth.

An analysis of similar data secured on black walnut plots failed to show any correlation between pH and walnut growth. This was true of all horizons.

SUMMARY

An investigation of physical and chemical soil properties as related to the growth of important tree species has been started at this Station with soil profile studies in 135 black locust and 120 black walnut plantation plots, to determine those properties which influence most significantly the growth of upland hardwoods.

From the data at hand it appears that the growth of locust and walnut is closely correlated with those properties of the subsoil - plasticity, compactness, and structure - which influence drainage and aeration. Both species appear to react very similarly and unfavorably to insufficient drainage or to excessive drainage.

This preliminary investigation has failed to show significant correlation between tree growth and degree of soil acidity or amount of chemical elements, either for locust or walnut. It is recognized that if data had been available for sites where plantations of these species had failed entirely, more significant results might have been obtained.

It is planned to extend the initial phase of this investigation summarized in this progress report by further studies of the behavior of these and other important tree species in planted and natural stands under the variety of site conditions found in the region, with supplemental fertilizer studies. For successful reforestation or forest management knowledge of the silvical characteristics of tree species is inadequate without equal knowledge of the sites on which they grow.

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